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WOOD FIRED HYDRONIC HEATING SYSTEM

Canada

91-06291/

WOOD FIRED HYDRONIC HEATING SYSTEM

Prepared for:

Canada Mortgage and Housing Corporation

Project Implementation Division

682 Montreal Road

Ottawa, Ontario

K1A 0P7

Prepared by:

Wilfred Sorensen, Architect
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Canada Mortgage and Housing Corporation
Société canadienne d'hypothèques et de logement
Canadian Housing Information Centre
Centre canadien de documentation sur l'habitation

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ELECTRIC-FREE WOOD FIRED HYDRONIC HEATING SYSTEM

Prepared for:

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682 Montreal Road
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Prepared by:

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MARCH 1989

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TESTING AND ANALYSIS OF AN ELECTRIC-FREE WOOD FIRED HYDRONIC HEATING SYSTEM

March 1989

ABSTRACT

With financial assistance from the Housing Technology Innovation Program of Central Housing and Mortgage Corporation an Electric-Free Wood Fired Hydronic Heating System was designed, built and tested in a house near Kingston in 1988 and early 1989.

During the first formal test all components were working when the fire was small but at a high rate of firing the bubble pumped boiler did not pump at a sufficient rate to maintain the pressure of the working fluid within safe limits. Steam had to be released constantly with the result that very little energy was delivered to the distribution system and the storage tank. To overcome this difficulty a bubble pump external to the boiler was constructed and installed. A number of leaks in the boiler and in the heat exchanger were repaired.

A preliminary test firing indicated that this modified design worked very well. For a short period of time approximately 90,000 BTU/hr was being delivered to the storage tank.

A second formal test ended inconclusively because of leaks. The design flaws which are causing the leaks are being corrected in order to retest the system at some future time.

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TESTING AND ANALYSIS OF AN ELECTRIC-FREE WOOD FIRED HYDRONIC HEATING SYSTEM

INTRODUCTION

"Wood Hydronica" is the tradename of a hydronic wood burning heating system which incorporates an attractive fireplace, a bubble pumped boiler, a heat storage medium and a heat distribution system using low pressure vapour. The advantages which are aimed for are high efficiency, a clean burn, visual delight, heat storage and hence the freedom from the need for a continuous fire, a noiseless distribution system, and independence from the power grid.

The fireplace is located in the living room. This location is important not for a functional reason but for an aesthetic reason and as such the location is fundamental to the total system. The fire could be located in the crawl space where it could deliver heat to the storage tank by a fluid flowing through piping by convective forces. Such a system would not be novel. Nor would it have any appeal.

In a system incorporating a large heat storage tank in the crawl space only the "Wood Hydronica" system with its bubble pumped boiler enables the cheerfulness of the fire to be enjoyed in the living room.

1. The Components

The components of the Electric-Free Wood Fired Hydronic Heating System which was built are as follows:

1. A steel stove with tight-fitting doors glazed with transparent ceramic
2. A well insulated chimney
3. A boiler mounted at the top of the chimney
4. A bubble pump mounted atop the boiler
5. A heat exchanger/vapour generator
6. Piping between the heat exchanger/vapour generator. The working fluid in the boiler, the heat exchanger/ vapour generator and in the piping connecting these components is a 50/50 mixture of water and glycol antifreeze
7. A large water storage tank in the basement
8. A heat distribution system with convectors in each room. The working fluid in this system is distilled water
9. A domestic hot water tank
10. A manually operated control valve

These components were installed in a 2 1/2 story house 40 km north-west of Kingston, Ontario. A schematic drawing of the heating system elements appears in Appendix "B".

2. Method of Operation

The stove portion of the "Wood Hydronica" Heating System is intended for a good sized, fast burning fire. The intention is not to use the stove as an air-tight appliance since this mode causes air pollution and creosote build-up in the chimney.

On a typical winter day a fire is started before supper and burns briskly. Fuel is added four or five times throughout the evening to maintain a hot fire. An hour or so before retiring the last fuel is added and the fire is allowed to burn out.

Because excess heat is stored in a cistern full of water, no fire need be lighted till the following evening.

The working fluid in the boiler is freeze protected. All air has been removed from the fluid so that corrosion from within the system is negligible and the system is under a partial vacuum even when there is a fire. On account of the vacuum the operating temperature of the fluid is below 190°F, well within the range that will give the antifreeze a long life. A minimum 5 year life of the fluid is expected.

Periodic cleaning of the boiler is desirable for maximum efficiency but cleaning of the flue should not be necessary.

There are no motors or pumps to require servicing.

3. How the System Works

a) The Fireplace

The fireplace is essentially a well insulated cylindrical steel drum of 1200 mm diameter recessed into the chimney and having three glazed hinged doors on the side facing the living room. Combustion air enters at the left hand side of any or all of the doors and adjustable retainers control the width of opening of the doors. Generally two doors are tightly closed when there is a fire and the third door is cracked open about 6 mm. There is an unusually strong draft because the flue is well insulated and no heat is withdrawn from the gasses until they get to the top of the chimney.

Combustion air rushes into the fire box tangentially through the narrow crack at the door and sets the air and burning gasses spinning. Being hot and therefore lighter than the incoming air the burning gasses are drawn by centrifugal action to the centre of the circular space so that their angular velocity increases. This effect causes considerable turbulence and enhances combustion. The cool incoming air from the room circulates at the perimeter of the firebox gathering some heat from the steel drum and the glazed doors. This heat transfer prevents the overheating of these surfaces by the radiation of the fire and preheats the combustion air to some extent.

Air drawn from the living room enters the house at cracks and through the fabric of the house.

b) The Heat Collecting System

Hot flue gasses from the living room fireplace pass through the boiler located at the top of the chimney. The working fluid in the boiler becomes hot (about 180°F) and rises to the bubble pump where it boils and produces vapour bubbles. The working fluid is pushed ahead of rising bubbles of vapour, falls over a dam and drains down a pipe leading to the heat exchanger located alongside the storage tank in the crawl space.

After giving up heat to the distribution system and to the water in the storage tank, the working fluid is piped back up to the condenser of the bubble pump where it picks up the latent heat of the vapour bubbles formed in the bubble pump. Becoming pre-heated, it is then piped down to the bottom of the boiler to begin the cycle again. (See Appendix "C" for explanation of the bubble pump)

c) The Heat Exchanger/Vapour Generator

At the heat exchanger/vapour generator sensible heat from the working fluid of the boiler passes firstly into the water of the distribution system. Any energy left in the working fluid then passes into the water of the storage tank. (See Appendix "D" Schematic of Heat Exchanger/Vapour Generator)

d) The Distribution System

The distribution system is a sealed system of piping leading from the vapour generator to the convectors, one in each room of the house. When the system is commissioned all air is pumped from the distribution system and the water it contains. Only the vapour generator is filled with water; the distribution piping and the convectors contain only water vapour and a small amount of condensed water trickling back to the vapour generator.

Because of the partial vacuum in the distribution system heat added to the water in the vapour generator causes it to boil almost immediately thereby producing vapour. This vapour rises through the distribution system to the convectors where it condenses and gives up latent heat. The condensate returns to the generator via the same piping which brings the vapour to the convectors. Here the condensate picks up heat and repeats the cycle again.

e) The Domestic Hot Water System

Part of the vapour produced in the generator is lead by a separate pipe to a heat exchanger alongside the domestic hot water tank. Cold water from the bottom of the tank enters the heat exchanger, gains heat, rises by convection through the heat exchanger and re-enters the tank at the top. On the warm side of the heat exchanger vapour gives up its latent heat, condenses and trickles back to the generator.

f) The Heat Storage Tank

In the crawl space is located a 4,550 l (1,000 gallon) pre-cast concrete water storage tank. Alongside this tank is a smaller plywood tank which contains the heat exchanger/ vapour generator and 1490 l of water. Connecting the two tanks are two pipes of 75 mm in diameter, one near the top, one near the bottom, which permit water to flow from one tank to the other by convection. Both tanks are well insulated on top, bottom and four sides. Both tanks are also lined on the inside by a water and vapour resistant plastic sheet material.

g) Future Solar Component

Provision has been made for incorporating into the system energy from solar collectors to be installed on the roof in the future. A heat exchanger at the domestic hot water tank and another in the plywood box have been installed at this time since it would be difficult to do so later. Energy from the solar collector system will first be directed into the domestic hot water tank and any residue energy is directed into the water in the cistern.

CONSTRUCTION METHODS

The lack of electric power at the site proved to be a great inconvenience which was not fully appreciated in the planning stage. Battery powered hand tools were used where possible.

Testing of piping for air tightness was accomplished by filling the systems with water, putting a vacuum on and listening for air leaks with a stethoscope. The vacuum was produced by heating an old hot water tank partly filled with water on a wood or gas stove, expelling all air by boiling the water, closing the valve and waiting for the tank to cool. When a positive pressure was needed the same tank was brought to a service station in a nearby village and pumped up with air.

The one large valve on the distribution system gave much difficulty due to a flaw in its' manufacture.

A design flaw in the boiler caused stresses which cracked a weld at a point which was exceedingly difficult to access.

OBSERVATIONS

The first test showed that certain assumptions about the boiler design were incorrect. There was insufficient flow induced in the boiler tubes which caused them to empty of water and fill with vapour.

There are a number of theories as to the reason for this which will in due course be put to the test.

A separate bubble pump was built and installed on top of the boiler; boiling in the tubes of the boiler was suppressed and an adequate flow was achieved.

During the most successful informal test firing, achieved during a period when there were no leaks, pumping action was steady and the vapour pressure at the top of the system was - 16" Hg which corresponds to a fluid temperature of 183°F. The flowmeter showed flow varying from 1.0 to 1.8 U.S. gal/minute, averaging 1.4 U.S. gal/min.

The heat delivered = rate of flow x specific heat of fluid x temperature difference of fluid. The temperature of the fluid returning to the boiler was estimated by the author holding his hand on the return pipe. For the brief period observed, approximately half an hour, the heat delivered was approximately 1.4 U.S. gal/min x 0.9 (for 50/50 glycol/water) x (183-55) = 90,000 BTU/hr.

The water in the plywood tank was felt to be about 110°F for about 2" depth while the distribution piping was too hot to be touched for a distance of about 4' from the top of the vapour generator.

Unfortunately the system did not perform as well during the subsequent formal testing due to start-up problems. (See Appendix "A" Performance Test)

CONCLUSIONS

While the testing was inconclusive it is believed that the problems which exist can be overcome and that the system will perform as expected. In retrospect it would have been easier to test the system at our laboratory. The lessons learned working at the site will not go unheeded; when production of the wood Hydronica System begins it will be a factory made product which will be fully assembled and loaded onto a flat bed truck, chimney, fireplace, storage tank, boiler and bubble pump. A crane will put the completely charged and tested system into place alongside a house.

Appendices

"A" Performance Test - Wood Fuel "Bubble Pump" Heating System by R.E. Wright, P. Eng. March 10, 1989

"B" Schematic Drawing of System

"C" Schematic of Bubble Pump

"D" Schematic of Heat Exchanger/Vapour Generator

"E" Design Calculations

"F" Photographs

PERFORMANCE TEST

WOOD FUEL "BUBBLE PUMP" HEATING SYSTEM

Submitted to:

Mr. Wilfred Sorensen, Architect

R.E. Wright, P. Eng.
127 College Street
Kingston, Ontario
K7L 4L7

March 10, 1989

1. OBJECTIVE

The objective of this work was to measure the thermal performance of the novel wood fueled heating system described below.

2. KEY DESIGN FEATURES OF HEATING SYSTEM

The heating system developed by Mr. Sorensen incorporates a number of novel design features that are worthy of note.

First, air inlets to the combustion chamber are designed so that a cyclone is established around the combustion zone. This ensures that combustion does not take place within 20 to 25 cm of the chamber walls. That this works well is evidenced by the complete lack of combustion residue on the chamber walls and viewing ports. The establishment of a cyclone is desirable too, since it promotes the mixing of oxygen and fuel which is a necessary prerequisite to addressing the difficult solid fuel carburetion problem.

Second, the heat exchange, which is located at the top of the flue, is physically removed by a distance of approximately 10 metres from the combustion zone. The flue is insulated to ensure minimum heat losses before the hot gases reach the boiler. This feature is important in that it results in long residence times for the products of combustion under conditions of high temperature. These long residence times and the good mixing of gases in the combustion chamber should result in a significant increase in combustion efficiency over what is achieved in more conventional designs.

Third, by using a perculator tube to move heat from the heat exchanger to the heat storage tank, no electrical or external mechanical energy is required. This has obvious advantages both for remote locations and for reliability.

Fourth, by using a simple hot water, heat storage unit, both domestic hot water and space heating needs can be met independent of the state of the combustion process.

3. METHODOLOGY

3.1 Introduction

The methodology described below was intended to provide a relatively accurate assessment of the overall input/output efficiency and good insight into the combustion and heat exchange efficiency that make it up. Accurate measures of heat exchange efficiency in situ were not possible without the use of special equipment to analyze the composition of the exhaust gases. The location of the flue exit at the peak of the flue further made this impossible without the use of an elaborate scaffolding and platform.

3.2 Gross Input

Gross input was obtained by weighing the fuel sample and measuring its moisture content. Moisture content was obained by boring a 2 cm. hole through randomly selected pieces of wood in the fuel sample. The wood shavings obtained were immediately weighed on a balance scale (accuracy $\pm$ 0.1 gm) and then left overnight in an oven at 125°C. Each sample was then weighed again, stirred and left for a further three hours at 125°C. A final weighing verified that all moisture had been removed from the sample.

The fuel sample was maple and white birch that had been stored inside for a period of 18 months. Each piece was weighed on a postal scale (accuracy $\pm$ 5 gm) and then wrapped in a moisture proof bag. Each piece was numbered with a felt pen to ensure correct identification.

A value of 19,960 KJ/kg was used as the higher heating value for bone dry wood. This figure is obtained from various engineering handbooks under the assumption that the fuel is pure cellulose. Bomb calorimeter tests of the fuel sample were not performed but experience has shown the value chosen to be within $\pm$ 2% of what is obtained experimentally for non-resinous wood.

Gross energy available in the fuel sample is calculated by converting the higher heating value to the lower heating value and then adjusting this value according to the moisture content of the fuel.

3.3 Net Heat Supplied

Heat is transferred from the heat exchanger at the top of the flue to two water storage tanks in the basement of the house. These tanks were measured and for convenience designated tank 1 and 2.

Since the tanks were rectangular, volume was easily obtained by measuring length, width and then the depth of water in each. Temperature was measured using an Omega 871A meter with an eight foot length of type K thermocouple wire sealed in a 2 m length of 12.7 mm ABS tube, leaving only the thermocouple junction exposed. Temperature readings were taken at 3 cm intervals over the depth of the tank to develop a temperature profile. Measurement of this profile during combustion enables an accurate figure to be calculated for the net output of the system.

3.4 Flue Gas Temperature

Flue gas temperature was measured at the inlet and outlet of the heat exchanger using the Omega meter and two, constructed for purpose, high temperature type K thermocouple probes with 6 m of wire on each to permit remote observation. It was intended that these probes be installed in the flue and the wires fed through an upstairs room window so that temperature could be monitored without constantly climbing to the roof. The temperature differential over the heat exchanger and an assumption regarding the composition of the flue gas can be used to provide an estimate of thermal efficiency.

3.5 Heat Content of Flue Gas Condensate

It was intended to gather a sample of the flue gas condensate at the inlet and outlet of the flue. The heating value of these samples would be measured in a bomb calorimeter, enabling some very general conclusions to be reached regarding combustion efficiency. In addition, depending upon the heating value, some general conclusions could be reached regarding the potential for flue fires and thus the safety of the system.

4. RESULTS

4.1 Introduction

An attempt was made to test the performance of the system on January 22, 1989. Although combustion was established, the heat exchanger did not function correctly. No reason could be found for the malfunction and some redesign and testing will probably be necessary in order to establish the cause. Cycling among the heat exchanger tubes is a likely cause. This could be corrected by the installation of a one way valve in each tube or by a change in design philosophy to a fire tube heat exchanger. There is no theorectical reason that precludes the eventual successful operation of the system.

4.2 Gross Input

The results and calculations of moisture content are shown in Table 1 below:

TABLE 1

MOISTURE CONTENT OF FUEL SAMPLE

SAMPLE	INITIAL WEIGHT (gm)	DRY WEIGHT (gm)	MOISTURE CONTENT (%)
1	33.4	29.1	12.9
2	26.5	22.5	15.1
3	34.1	29.4	13.8
4	29.8	25.2	15.4
5	31.3	26.8	14.4
6	35.6	30.2	15.2
		AVERAGE	14.5

TABLE 1 (Continued)

SAMPLE CALCULATION (SAMPLE 1)

$$\text{MOISTURE CONTENT (\%)} = \frac{(33.4 - 29.1)}{33.4} \times 100 = 12.9$$

The fuel sample weights are shown in Table 2 below.

TABLE 2

FUEL SAMPLE MASS

PIECE	MASS (gm)
1	1063
2	1474
3	723
4	652
5	1934
6	2537
7	2084
8	2459
9	1673
10	2346
11	2533
12	2608
13	1907
Kindling (Spruce)	1136

The fire was lit at 1643 hours using the kindling, and pieces 3, 4, and 9. The fire lit easily and quickly established a strong, turbulent flame front. At 1646 hours piece 13 was added, at 1648 pieces 1 and 2 were added and at 1650 hours piece 12 was added.

At 1652 hours the inlet temperature at the heat exchanger was 258°C and the outlet was 111°C. At 1654, piece 10 was added to the combustion chamber. At 1700 the outlet flue gas temperature was measured at 282°C and it had become clear that heat was not flowing to the storage tank. At 1703 hours inlet temperature of the flue gases was measured at 377°C and the outlet at 244°C. No flue gas temperature readings were taken after this time.

Based upon a rough estimate of the fuel consumed over a 20 minute period, it was clear that the heat output of the combustion process, based upon an assumption of 80% combustion efficiency, would be in the order of 70 kw thermal.

4.3 Net Heat Supplied

Tank 1 was found to contain 3783.2 litres of water at a temperature of 3.5°C with no detectable thermal stratification. Tank 2 was found to contain 1261.6 litres of water at 3.0°C, once again with no detectable thermal stratification.

Assuming a useful working range for domestic hot water and space heating from 45°C to 95°C and assuming a thermal efficiency of 80%, approximately five hours would be required to charge the storage tank once it had been exhausted. A fully charged tank should carry the house a minimum of 24 hours under conditions of design heat loss.

Since the heat exchanger did not function, none of these assumptions could be empirically verified.

4.4 Flue Gas Temperature

Flue gas temperature readings are shown in Section 4.2. Because flow in the system could not be established, no conclusions regarding thermal efficiency could be reached.

4.5 Flue Gas Condensate

Insufficient amounts of condensate were available. Observations of the flue gases at the exit point support earlier conclusions regarding combustion efficiency and the resultant lack of condensation in the flue gases.

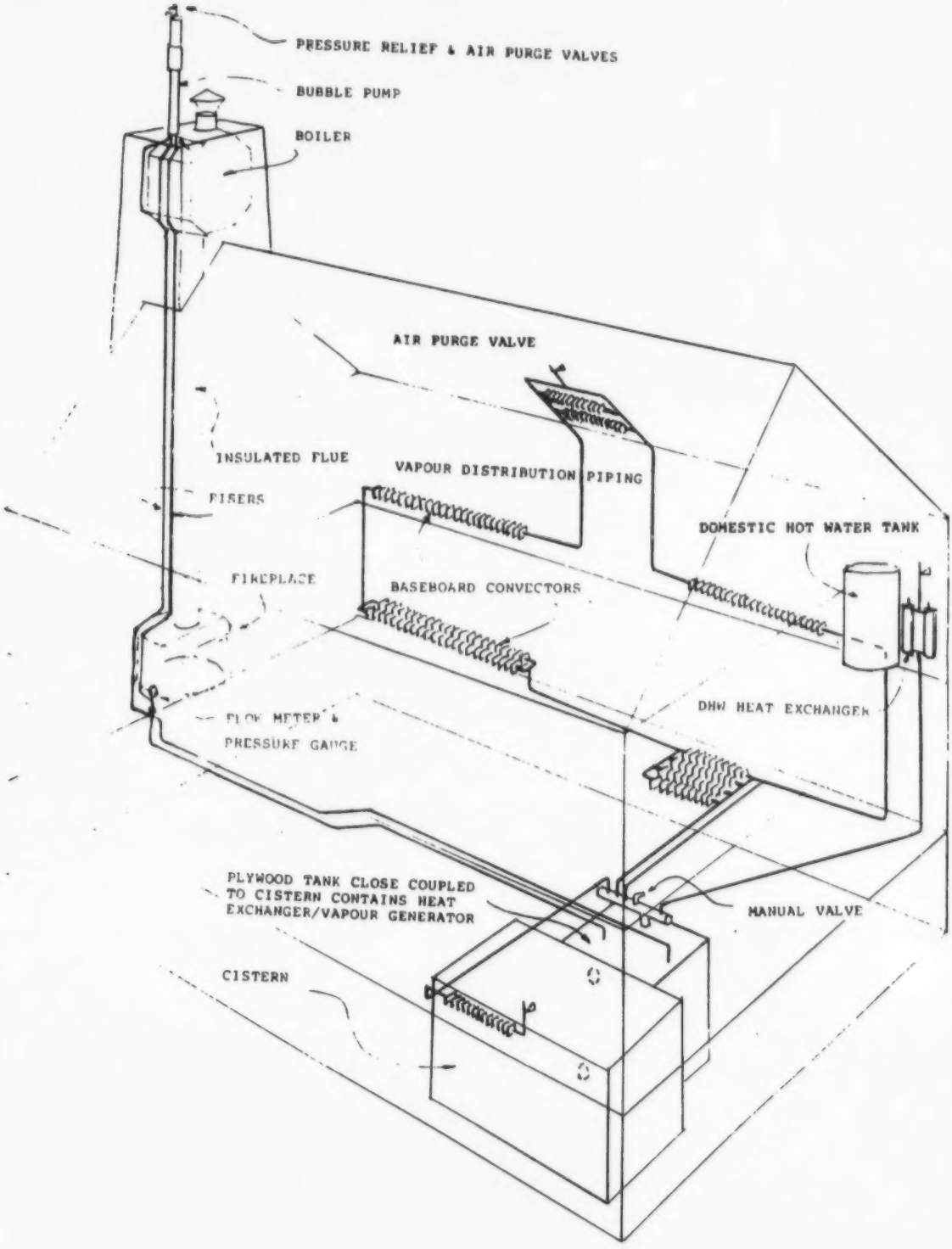
4.6 Second Trial

A second fuel sample was prepared and a second trial was conducted on 7 March 1989. Once again, flow could not be established initially and it appeared that the fluid in the system was cycling in the liquid tubes in the boiler unit. This is a logical explanation for what occurred at the initial test and if correct, it is a design inadequacy that is easily corrected. To test this hypothesis, some of the working fluid was drawn off at the bottom of the system in an attempt to establish a flow pattern in the heat exchange loop from the boiler to the heat storage tank. Flow in the system was almost immediately established, thus supporting the hypothesis. Unfortunately, since so much heat had been lost before flow was established, the test results could not be used and the rest of the trial had to be cancelled.

5 CONCLUSIONS AND SUMMARY

As noted earlier, there are no theoretical reasons why the concept should not function as predicted. The concept has been shown to work in lower output, solar applications. After initial start-up difficulties, the system worked well during the second trial, although no meaningful measure of performance could be obtained.

The design of the combustion system is worthy of a final note. Although many manufacturers of wood fueled space heaters make claims of achieving thermal efficiencies of 80%, previous extensive work by the author has shown that most achieve overall input/output efficiencies in the order of 50%, suggesting combustion efficiencies in the order of 60%. Poor combustion efficiency results in fuel consumption higher than necessary, the release of carcinogenic aromatic hydrocarbons into the atmosphere and a safety hazard posed by the build-up of these hydrocarbons, unburned, in the flue. It would be extremely instructive to carry out an analysis of the Bubble Pump design over some period of time in order to verify the performance improvements that it promises.



SCHEMATIC DRAWING OF SYSTEM

Appendix "B"

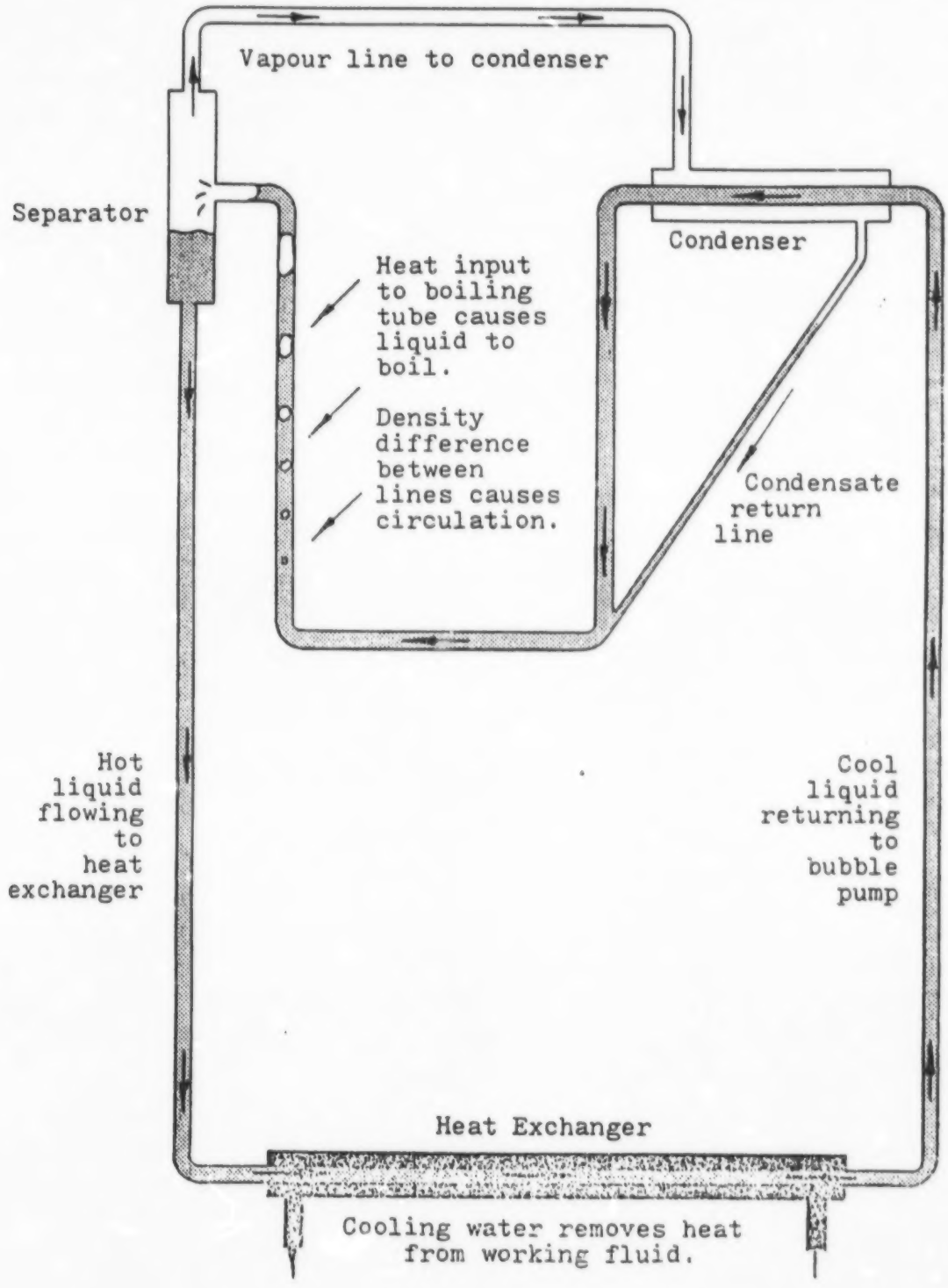
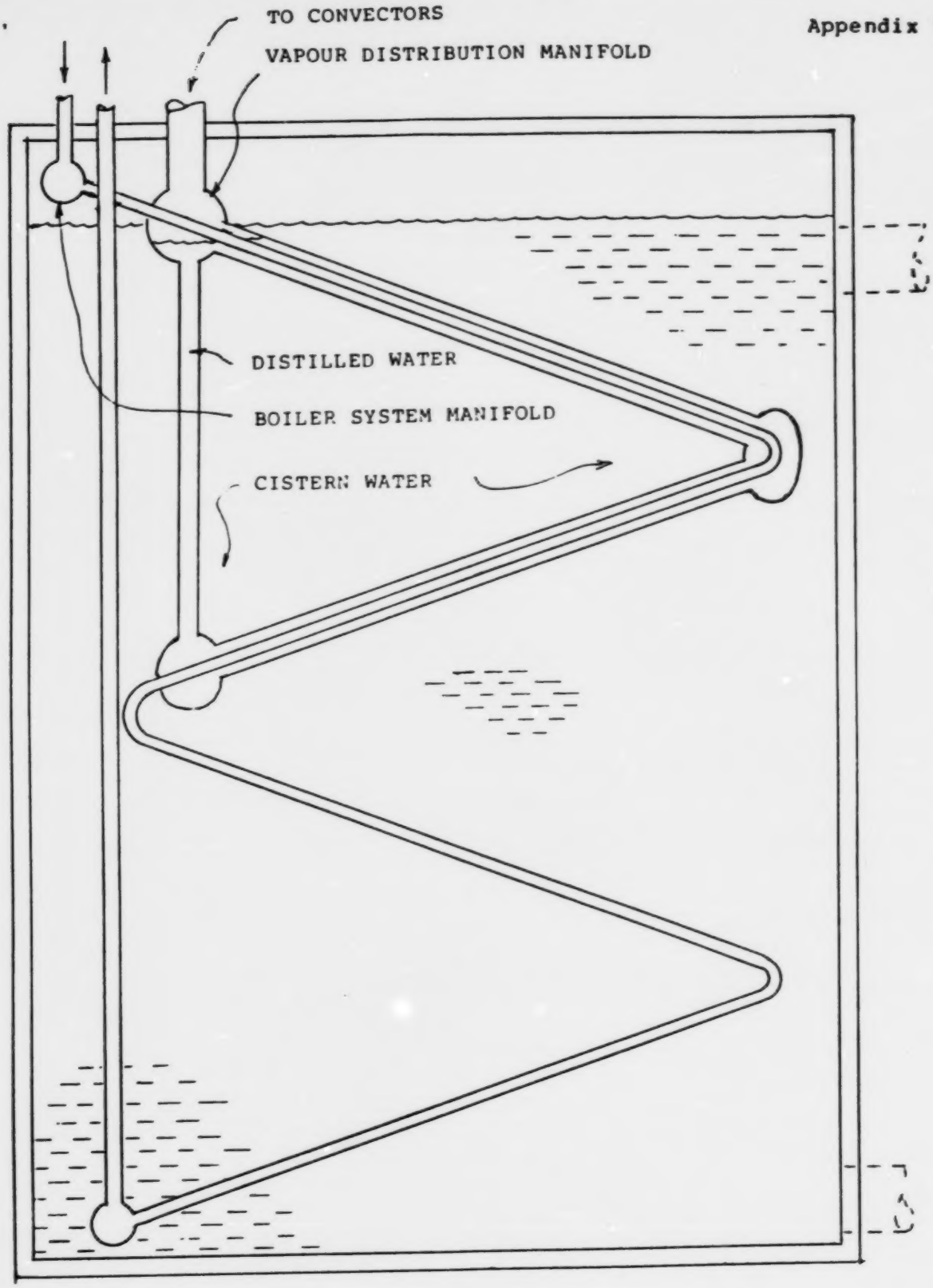

Vapour line to condenser
Separator
Condenser
Heat input to boiling tube causes liquid to boil.
Density difference between lines causes circulation.
Condensate return line
Hot liquid flowing to heat exchanger
Cool liquid returning to bubble pump
Heat Exchanger
Cooling water removes heat from working fluid.

FIGURE 1 : Operating Principle of a Bubble Pump



SCHEMATIC OF HEAT EXCHANGER/VAPOUR GENERATOR

Appendix "E"

DESIGN CALCULATIONS

The outdoor design temperature is taken as -15°F. The house to be heated measures 20' x 30' outside and is 2 1/2 stories high. The R values are estimated as follows:

1st floor:	11
2nd floor and attic:	20
Roof:	20

The crawl space is insulated with 2" foam insulation on the 8" concrete block foundation wall to a depth of 2 ft.

There are two panelled doors each with a storm door. Windows are double glazed and of moderate size.

Infiltration losses were taken as 10,000 BTU/hr.

Total design heat loss was calculated to be approximately 45,000 BTU/hr.

Heating System Calculations

To counter a design heat loss of 45,00 BTU/hr and give a reasonably short recovery time as necessary for a country weekend house a design output of 65,000 BTU was selected.

In addition,gaskets had to be upgraded and made thicker to accommodate differential movement of adjacent materials.

ALFRED'S HEATING SYSTEM — BUR OAK — MAR. 13/[illegible]

VAPOUR DISTRIBUTION SYSTEM

→ SELECT DESIGN STEAM TEMPERATURE - **160 °F** / 6.0 °C

WITH SATURATED STEAM : p = 4.7414 psia
V_f = 0.016305 ft³/lbm
V_g = 77.29 ft³/lbm (ρ = .0129
h_{fg} = 1002.2 Btu/lbm
μ_g = 0.012 centipoise (8.054 × 10⁻⁶ lb/ft·s)

→ DESIGN OUTPUT = 65,000 Btu/h = 64.8 lbm/hr.
= 0.0180 lbm/sec

→ DESIGN PRESSURE DROP = 1/2 psi (i.e. 72 psf,
(or 5,564 ft. of steam
(or 5° F !)

[1 psi = 11,129 ft. steam]

IF ΔP < 1/2 psi is economical, go for it.

→ START AT SECTION A - (2)

L = 20' = min. half-times

$\dot{m}$ = $\frac{10000}{1000 \times 2}$ = 10 lb/hr. = 0.0028 lbm/s

FOR 3/4" TUBE (= 0.0625 ft.)

$V = \frac{\dot{m}}{\rho A}$ = 70.75 ft/s

$R = \frac{\rho V D}{\mu}$ = 7000 f = 0.034

$\therefore h_f = 0.034 \times \frac{20}{0.0625} \times \frac{(70.75)^2}{64.4}$ = 845 = 0.076 psi

TEN ½" TUBE (D = 0.0417 ft.)

$V = \frac{m}{\rho A} = 159$ ft/s

$R = \frac{\rho V D}{\mu} = 15,500$ $\quad f = 0.03$

$\therefore h_f = 0.03 \times \frac{20}{0.0417} \times \frac{(159)^2}{64.4} = 5549 = 38.5$ psi

TEN 1" TUBE (FOR B-5) (D = 0.0833')

$V = \frac{m}{\rho A} = 39.8$ ft/s

$R = \frac{\rho V D}{\mu} = 5,200$ $\quad f = 0.037$

$\therefore h_f = 0.037 \times \frac{20}{0.0833} \times \frac{(39.8)^2}{64.4} = 218.5 = 0.02$ psi

→ NOW LOOK AT (4)-(5) (10')

$m = \left(\frac{15,000}{2} + 10,000\right) / 1000 = 17.5$ lb/hr $= 0.0049$ lb/s

CONSIDER 1" FILL TUBE (D = 0.0833')

$V = 69.1$ ft/s

$R = 9200$ $\quad f = 0.031$

$\therefore h_f = 0.031 \times \frac{10}{0.0833} \times \frac{(69.1)^2}{64.4} = 276 = 0.025$ psi

→ SECTION ①-② (use 20')

$m = 50$ lb/hr $= 0.0139$ lb/s

TRY 1½" TUBE ($D = 0.125'$)

$V = 87.7$, $FR = 17,500$ $f = 0.027$

$\therefore h_f = 0.027 \times \frac{20}{0.125} \times \frac{(87.7)^2}{64.4} = 516$ $= 0.046$ psi

THUS $\Delta P_{SYS.} = 0.121$ psi ±

→ LINE TO D.H.W. H.E. (use 20')

$m = 15$ lb/hr $= 0.00417$ lb/s

TRY 1" TUBE ($D = 0.0833'$)

$V = 59.27$ $FR = 7900$ $f = 0.032$

$\therefore h_f = 0.032 \times \frac{20}{0.0833} \times \frac{(59.27)^2}{64.4} = 419$ $= 0.0375$ psi

TO: W. Sorenson

HEAT EXCHANGER/VAPOUR GENERATOR

FROM: P.H. Oosthuizen

DATE: March 11, 1988

RE: Home Heating System

I have carried out a basic heat transfer analysis of the system shown schematically on the attached figure. This analysis indicates the following approximate mean heat transfer coefficients:

Inside Small Diameter Pipe $h = 55$ btu/ft^{2}hr$^\circ$F

In Annulus $h = 130$ btu/ft^{2}hr$^\circ$F

Outside Small Diameter Pipe in Tank $h = 260$ btu/ft^{2}hr$^\circ$F

Outside Annulus in Tank $h = 240$ btu/ft^{2}hr$^\circ$F

Based on these values, we estimate that when the system is first started, about 50,000 btu/hr will be passed to the home heating system and about 50,000 but/hr will be passed to the water in the tank. As the water at the top of the tank becomes hot, the heat input to the house will rise to about 65,000 btu/hr. With the tank fully heated and no heat input from the fire the heat input to the house will be about 50,000 btu/hr.

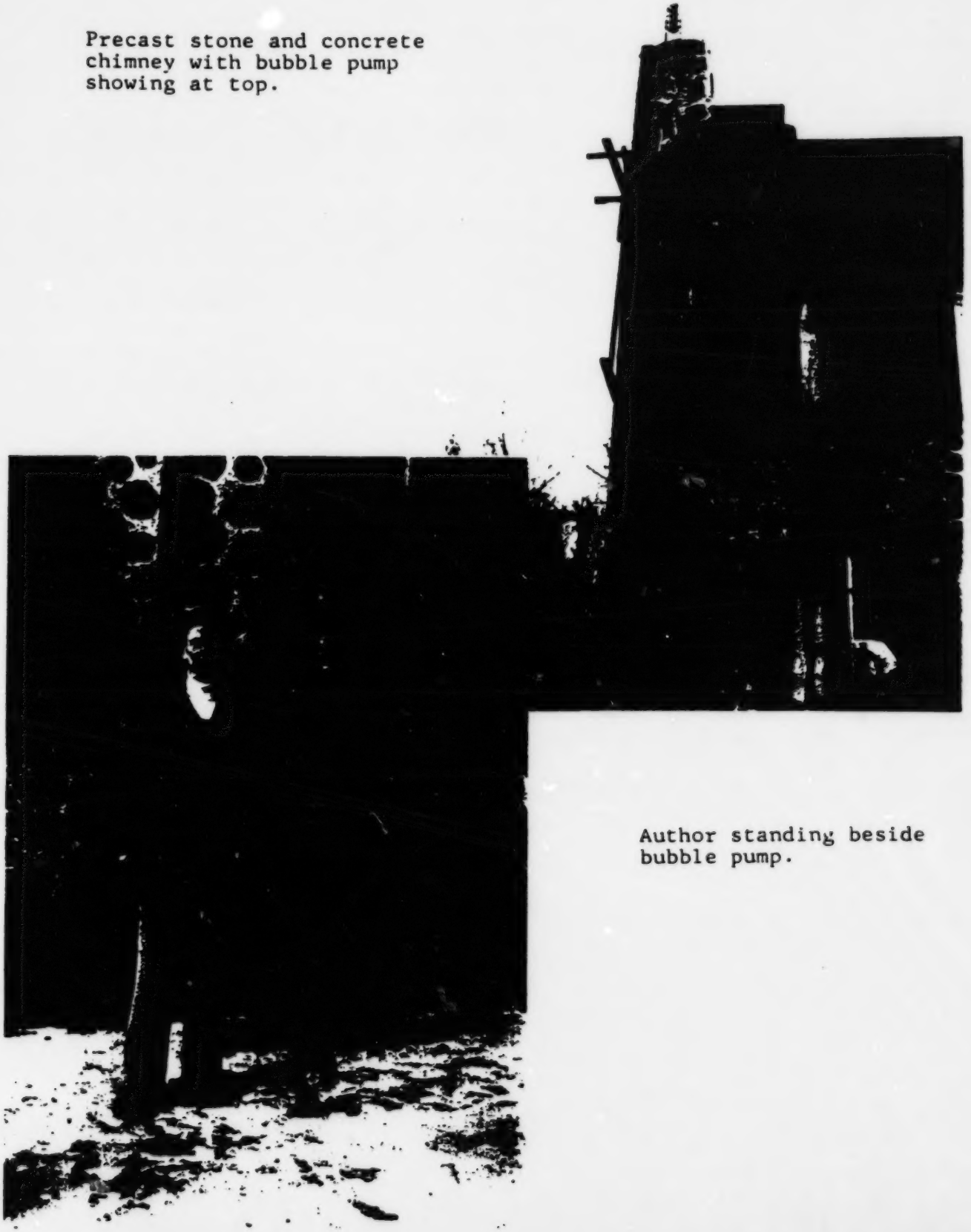
We must stress that the above values are relatively crude but that improvements would require computer modelling and more information about the bubble pump characteristics and the home heating system.

In giving the above values, I in no way am able to guarantee that the system will operate successfully since the operation is dependent on the interaction between all components. Furthermore, I must stress that great emphasis should be placed on safety when implementing the system but that I have not examined this aspect of the system at all.

I hope the above is satisfactory to you. I would ask that you arrange reimbursement to me for the sum of $170 to cover my time and expenses in carrying out the work.

P.H. Oosthuizen

Precast stone and concrete chimney with bubble pump showing at top.



Author standing beside bubble pump.

Pressure gauge and flow meter mounted on cold riser leading up to boiler. Lower pipe conducts hot fluid down from boiler to Heat Exchanger/Vapour Generator in crawl space.

Blazing fire in 'Spinfire' fireplace in the living room.

Heat exchangers before positioning of DHW tank. The shorter pair is connected to vapour distribution system; the taller one to the future solar heating system.

Lower photo shows 60 gal. tank in place mounted on a stand. At lower left is a section of finned space heating element.

Bubble pump before addition of insulation. Working fluid is seen gushing from a bubble tube.

Upper part of heat exchanger/vapour generator mounted in plastic lined plywood box.